Mapping plant area index of tropical forest by Lidar: calibrating ALS with TLS

Grégoire Vincent, Jean Dauzat, Cécile Antin, Eloi Grau, S. Durrieu

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Grégoire Vincent[1], Cécile Antin[1], Jean Dauzat[2], Eloi Grau[3,4], Sylvie Durrieu[3]

[1]*IRD, UMR AMAP, Montpellier, 34000 France*
[2]*CIRAD, UMR AMAP, Montpellier, 34000 France*
[3]*CNES, UMR TETIS, Montpellier, 34000 France*
[4]*IRSTEA, UMR TETIS, Montpellier, 34000 France*

Highlights: We compare Plant Area Density (PAD) profiles derived from Terrestrial Laser Scanning (TLS) and contemporaneous Aerial Laser Scanning (ALS) in dense tropical forest. Poor sampling of the lower part of the canopy profile by ALS is mitigated by using a multiple resolution approach. Anisotropy of transmittance revealed by TLS allows further improvement of PAD estimates.

Key words: *TLS, ALS, fusion, Leaf Area Index, Tropical moist forest.*

Introduction

Leaf area Index (LAI, the one-sided green leaf area per unit ground surface area m²/m²) is a major driver of water and carbon exchanges and controls radiation extinction within the vegetation. It is therefore a key parameter in biogeochemical cycles and in vegetation dynamics. However, the measurement of Leaf Area Index in dense evergreen tropical moist forest is a considerable challenge. LAI estimates of moist tropical evergreen forests almost exclusively rest on indirect methods which all have serious limitations. Hemispherical photographs and optical devices such as the Leaf Area Meter LAI2200 are very sensitive to assumptions made on degree of clumping [1] and leaf angular distribution [2]. Besides, these methods do not allow distinguishing between photosynthetic and non-photosynthetic materials, leading to the estimation of PAI (Plant Area Index) rather than LAI. Remote sensing indices (NDVI, EVI) typically saturate at high LAI values [3]. The ability of Lidar to measure forest 3D structure, with an unequalled level of detail at both tree and plot level using Terrestrial Laser Scanning (TLS) systems and over large area with a coarser resolution using Airborne Laser Scanning (ALS) systems, opens up new possibilities to assess this key forest variable.

Material an methods

Multiple-return ALS provides spatially accurate information on laser beam progressive extinction during its downward path through the canopy. Therefore it has obvious potential for LAI estimation. A number of studies using different approaches have been conducted to evaluate the potential of ALS for this purpose [4-6]. In the present study we took a slightly different stance from previous works by 1) bringing in more complete information on the return signal provided by an up-to-date Full Wave Form ALS system (Riegl LMS Q560) combined with 2) precisely georeferenced multiple-return TLS (Riegl VZ400) acquisitions.

Using aerial laser scanning, backscattered energy is digitized and post processed to identify distinct echoes whose 3D position and amplitude are recorded [7]. From this information the projected area of objects intercepted by the laser beams are estimated, conditional to a number of regularity assumptions about vegetation optical properties.

A statistical analysis of ALS data showed that c. 50% of the variability of vegetation returns amplitude was explained by the echo rank and the total number of returns detected. Ray tracking of all laser shots within a voxel space and localization of their echoes allowed determining a local vegetation transmittance which was used to estimate local vegetation density (PAD m^2/m^3). However in our data set almost one third of the canopy volume (at 1 m^3 resolution) was not sampled by any laser pulse optical path. In such case or in the case transmittance was null, local transmittance was recomputed from the next coarser resolution and the process iterated to fill in the gaps.

Conversely all canopy voxels were sampled by at least 1000 shots using our dense multiple TLS acquisitions protocol. However because TLS data suffer from a fundamental indeterminacy (the generally unknown fraction of a given pulse which may not have been intercepted) a slightly different algorithm was used to compute the transmittance from TLS data. Transmittance in any voxel was computed as the weighted mean ratio of returns per shot (where the weight is the shot path length within a voxel) and single shot transmittance is either 0 or 1.
TLS multiple station acquisition and resulting omnidirectional sampling also provided a way of exploring transmittance dependence on shooting inclination angle. We analysed the transmittance directionality by sub-

setting TLS shooting elevations per 10-degree steps and analysed transmittance per direction along the entire canopy height profile.

Results and perspectives

Plant Area Density (PAD) was estimated from transmittance values assuming a spherical distribution function of foliage elements. Vegetation vertical profiles (mean PAD per vegetation layer) were established for six quadrats of 24mx24m in the scanned area (Figure 1). Three different profiles are shown per quadrat: ALS derived profiles obtained with or without using the multi-resolution approach as well as the TLS derived profiles. Multi-resolution processing efficiently corrected for most of the discrepancies between ALS and TLS profiles occurring in the lower canopy which was under-sampled by ALS. PAI estimates from TLS and multiresolution appeared to be within 5% of each other at the spatial scale considered.

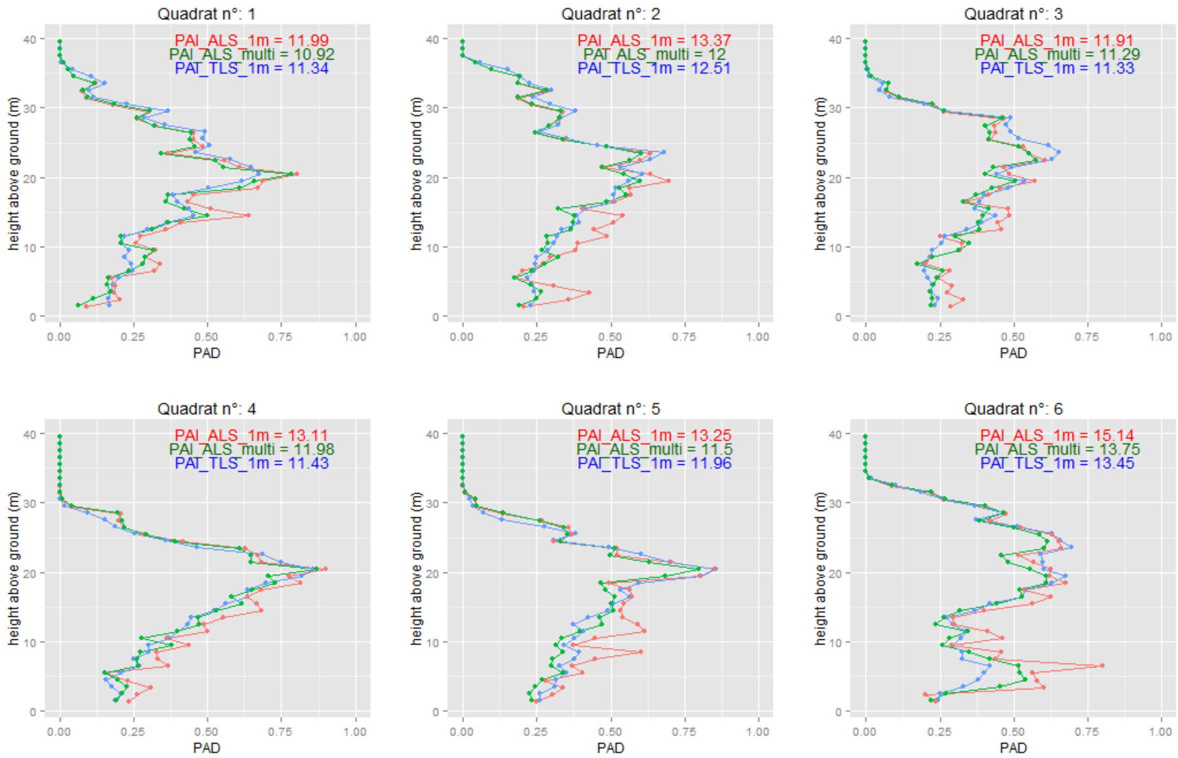

Figure 1: Vegetation density profiles (PAD) per 24mx24 m quadrats in dense tropical forest obtained either by Terrestrial laser scanner (TLS) or aerial laser scanner (ALS). Elementary volume (voxel) is 1 meter except for the ALS_multi case which uses mutiple resolution (here 1 to 4m) to fill in non sampled elementary voxels.

Variation in transmittance with inclination was found to be significant indicating that the actual leaf (or rather plant material) inclination distribution function was not spherical. Remarkably this anisotropic response was very similar from top to bottom of canopy. To evaluate the error made by assuming a spherical leaf inclination distribution function, we will adjust an ellipsoidal foliage element angle distribution and Plant Area Density to fit the observed directional transmittance values. The parameterized ellipsoidal distribution function will then be used to compute PAD from ALS data. The magnitude of the difference in PAD profiles resulting from the use of two leaf angle distribution functions will be estimated (underway).

Further improvement in ALS estimates may be obtained by taking into account the local variation in optical properties (reflectance) occurring between individual crowns. This should improve transmittance estimates from which PAD profiles are derived. Further developments will be needed to assess LAD profile instead of PAD profiles from both TLS and ALS data, e.g. by developing methods to separate foliage from large woody elements. Dense TLS sampling could then be used to evaluate the foliage clumping index to further improve LAI estimates.

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